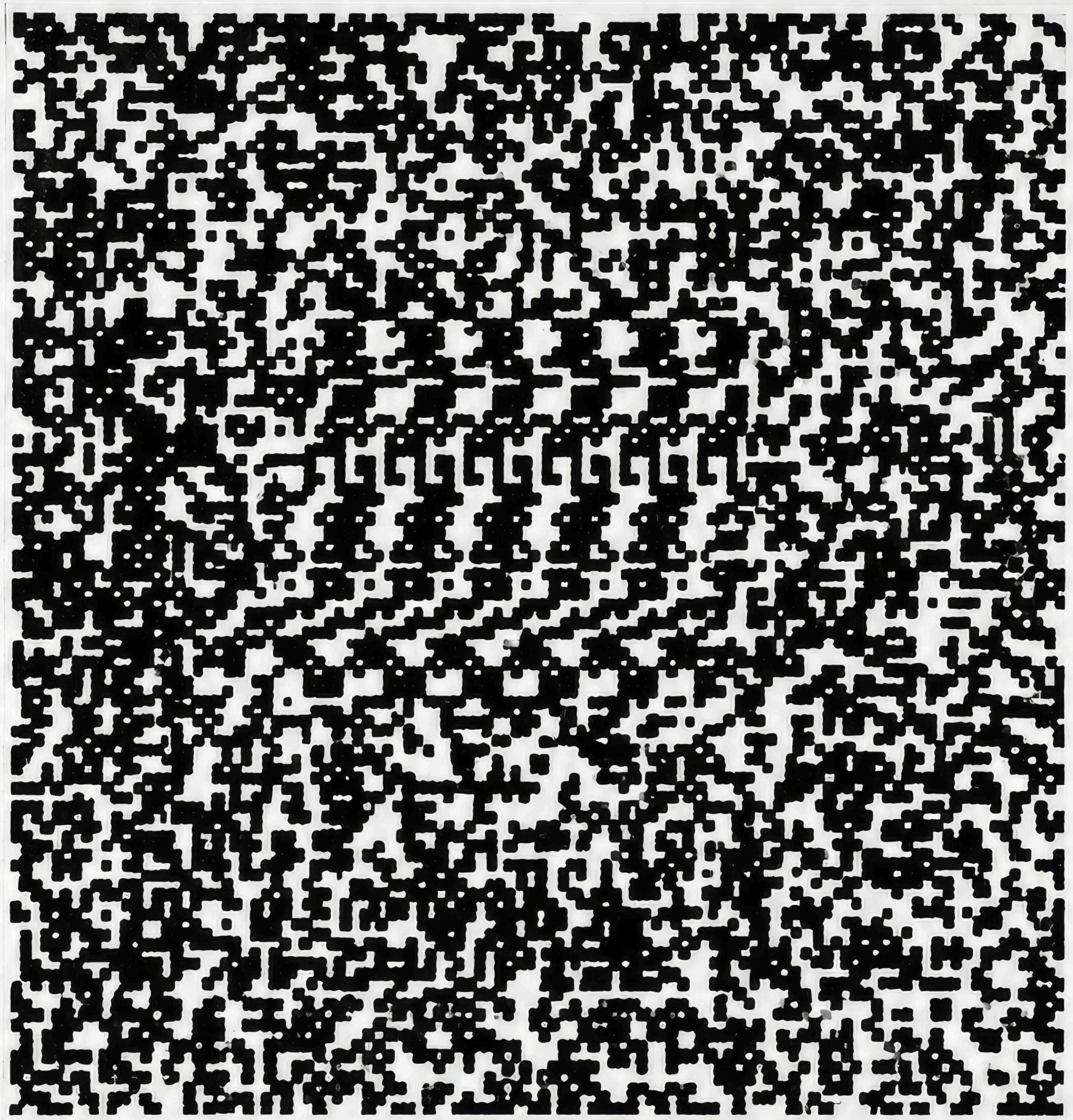
Bell Telephone Laboratories

Research and Development Unit of the Bell System

COMPUTER GENERATED STEREO IMAGES

DIGITAL RESTORATION, COMPENSATING FOR AGING/DAMAGE.

THE HUMAN USE OF COMPUTING MACHINES



JUNE

1966

BELL TELEPHONE LABORATORIES

COMPUTER GENERATED STEREO IMAGES

This souvenir paperweight is a computer-generated stereo image used to study perceptual performance. It is an example of a psychological phenomenon created at Bell Telephone Laboratories by Dr. Bela Julesz of the Sensory and Perceptual Processes Department.

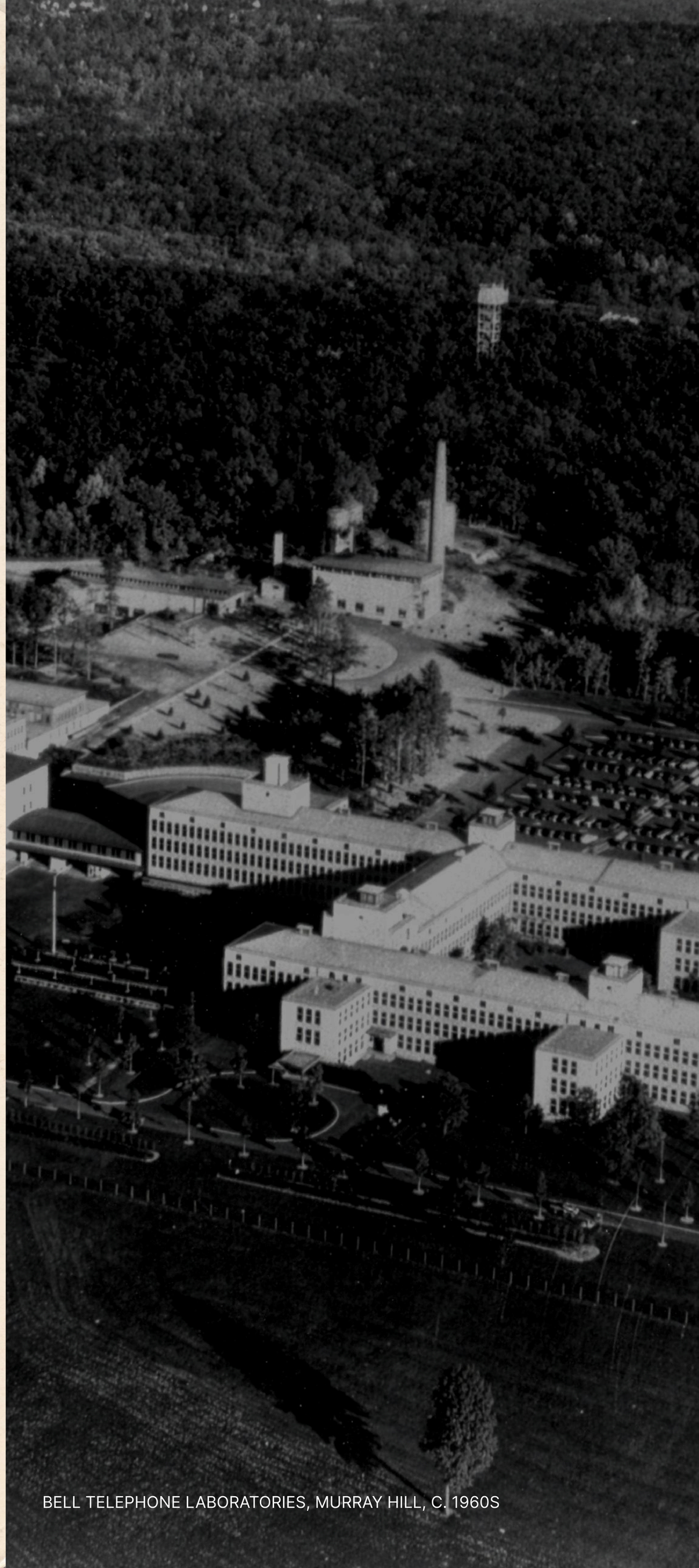
Using computers it is possible to create images with subtly controlled surface patterns. Random dot images are actually easier to see stereoscopically than real objects because each dot conveys depth information. Real objects, on the other hand, often have large homogenous areas without any indication of depth. For example, a disk is difficult to distinguish from a sphere without the presence of shaded areas and textured surfaces.

There are three stereo images visible within the paperweight. An upper area composed of black and white random dots stands out vividly and, similarly, a lower rectangular area appears behind its surroundings. In the center a square appears either in front or behind the surrounding area, depending on whether you look at the upper or lower area.

The image is reproduced on a Polaroid Vectograph® print with polarized dot patterns on each side of the print. Polarized glasses have lenses which match the polarization of the dot patterns—one pattern may be seen by looking through the lens of the right eyepiece and the other by looking through the left eyepiece. Thus, when viewed through both lenses simultaneously the image will be stereoscopic.

BELL SYSTEM

"Polaroid" and "Vectograph"® by Polaroid Corporation



BELL TELEPHONE LABORATORIES, MURRAY HILL, C. 1960S

“I don’t know who first used the electronic computer to produce patterns of some originality and interest, but it may have been Dr. Bela Julesz of the Bell Telephone Laboratories. In studying properties of vision, Dr. Julesz caused the computer to generate patterns of black and white dots within squares, in which just a little order was imposed upon randomness.”

PIERCE, JOHN R. SCIENCE, ART, AND COMMUNICATION. C. N. POTTER, 1968. P.150.

JOHN ROBINSON PIERCE AT NASA, 1952

DR. BÉLA JULESZ

A profound perceptual psychiatrist and a foundational pioneer behind the American computer art movement, Béla Julesz's (1928–2003) influence can be traced throughout the worlds of art and science, both in his lifetime and thereafter.

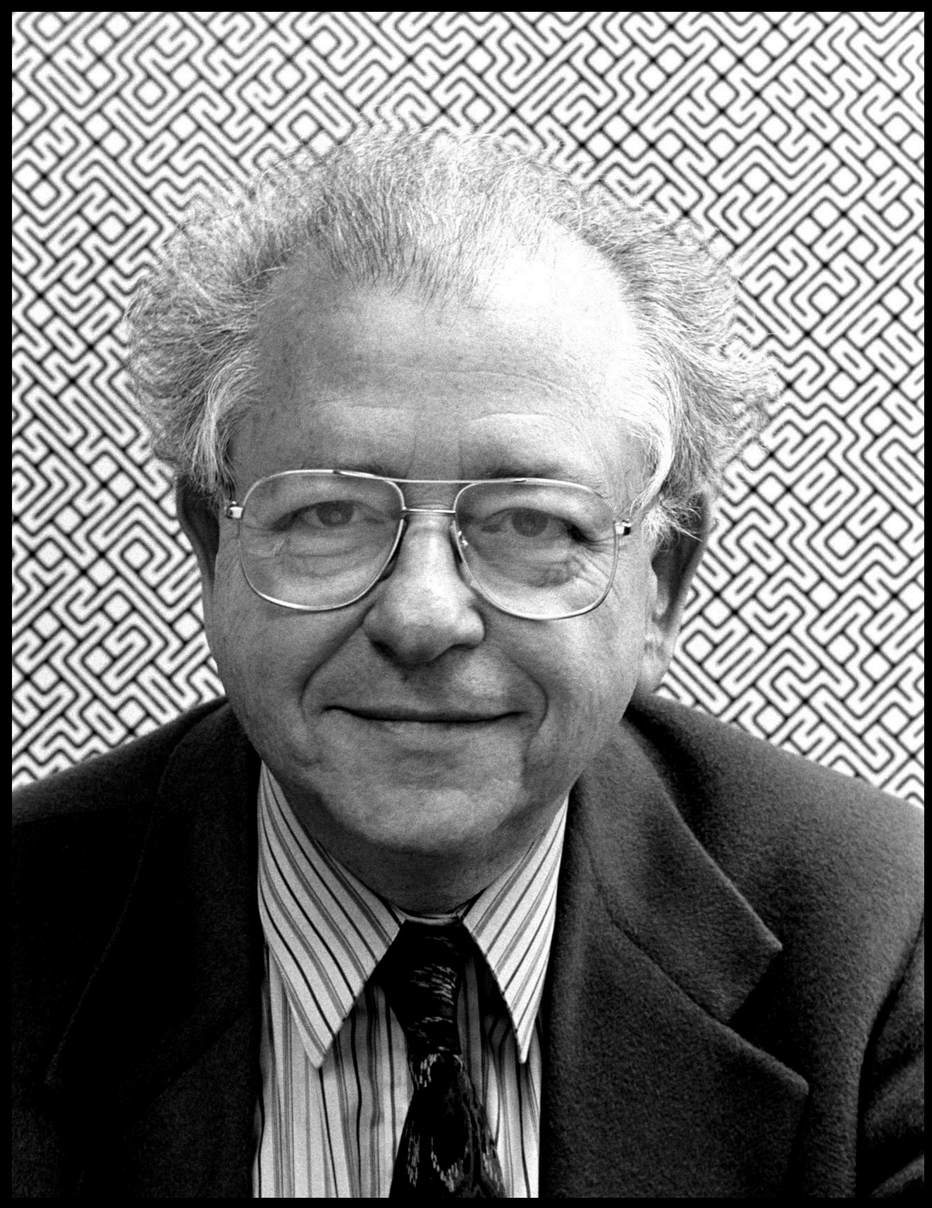
A research engineer at Budapest's Telecommunications Research Institute throughout the early 1950s, Julesz would concentrate his studies on signal processing and communications systems, ultimately completing his PhD dissertation on advanced radar methodology in the mid-1950s. Classified by the military shortly after, he would be forced to complete a secondary dissertation on TV bandwidth compression to earn his PhD. In the following months, Julesz would flee Hungary by river, swimming across with his wife and their most important possessions following the Soviet occupation.

Arriving in New York by the end of 1956, he would be hired by Manfred R. Schroeder to continue his doctoral studies on television signals at Bell Laboratories, where he would find consistent access to a computer for the first time. Exploring disparities in the consensus behind camouflage detection, he would shift his concentration of study to visual perception in 1959, where it would remain until 1989.

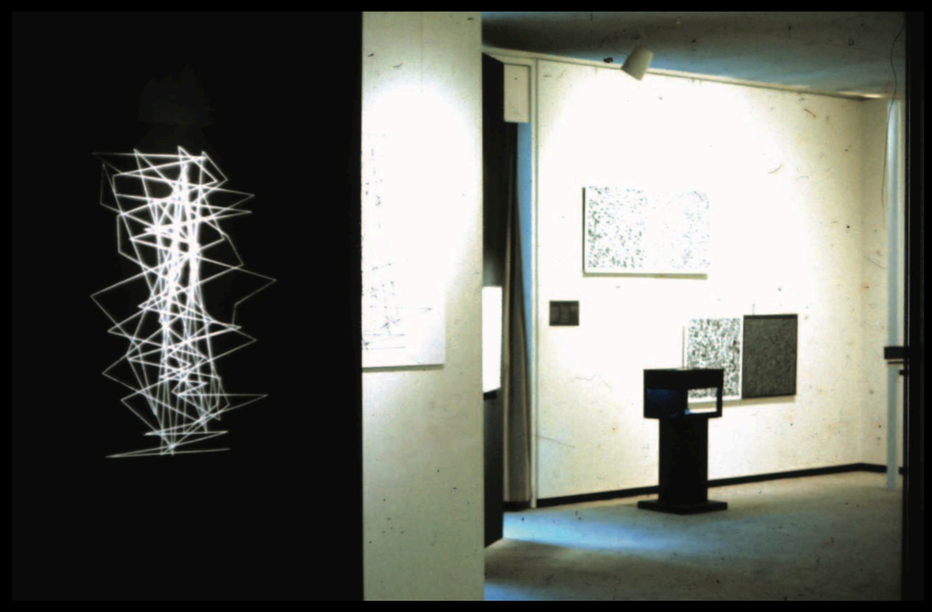
In a formal shift from scientist to artist, Julesz's computer-generated outputs would be presented as fine art in the historical Computer-Generated Pictures exhibition at New York's Howard Wise Gallery from April 8–24, 1965. Exhibited alongside the work of A Michael Noll, the exhibition survives as the earliest group exhibition of computer art in the United States.

"Although there was a disclaimer below my computer-generated stereograms and textures, which stated that they were merely the results of scientific experiments, and that their creator did not regard them as works of art, the newspapers disregarded it."

JULESZ, BÉLA. "DIALOGUES ON PERCEPTION." BEYOND ART: A THIRD CULTURE: A COMPARATIVE STUDY IN CULTURES, ART AND SCIENCE IN 20TH-CENTURY AUSTRIA AND HUNGARY, EDITED BY PETER WEIBEL, SPRINGER, 2005, P. 123



PORTRAIT OF BELA JULESZ, APPEARED IN PHYSICS TODAY OBITS, APRIL 2005, NICK ROMANENKO, RUTGERS PHOTO SERVICES, COURTESY AIP EMILIO SEGRÈ VISUAL ARCHIVES.



COMPUTER-GENERATED PICTURES, HOWARD WISE GALLERY, NEW YORK, USA (APRIL 8 - 24, 1965)

NOLL, A. MICHAEL. "THE HOWARD WISE GALLERY SHOW OF COMPUTER-GENERATED PICTURES (1965): A 50TH-ANNIVERSARY MEMOIR." LEONARDO, VOL. 49, NO. 3, 2016, PP. 232–39.

BÉLA JULESZ DEMONSTRATING THE METHOD FOR VIEWING COMPUTER-GENERATED IMAGES IN THREE DIMENSIONS, C. 1960S

KRANZ, STEWART. SCIENCE & TECHNOLOGY IN THE ARTS: A TOUR THROUGH THE REALM OF SCIENCE & ART. EDITED BY MARGARET HOLTON AND ELIZABETH S. FOWLER, VAN NOSTRAND REINHOLD, 1974, P. 91.

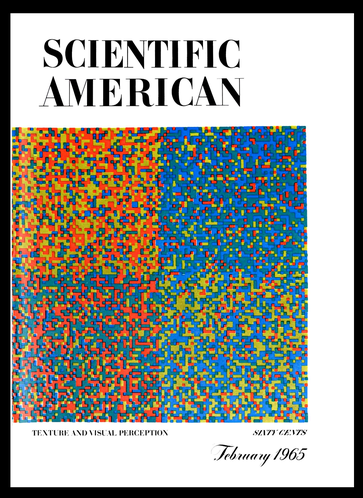
DR. BÉLA JULESZ

Throughout the early 1960s, Julesz would rely heavily on the computer in his explorations of visual perception, publishing his findings across an array of print media. Through this process, his ideas would expand far outside of the scientific community and not only enter but directly influence that of the artistic. One of the great artistic minds to be influenced by Julesz in this period would be Salvador Dalí, who had encountered the Computer-Generated Random Dot Stereogram through Scientific American in 1965. Dalí would execute a number of works based on Julesz's computer-generated outputs, even instructing his studio staff to study his writings specifically.

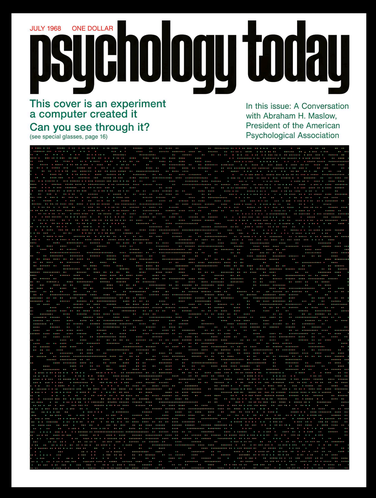
Not all influences were so wholesome. Some years later, Julesz, along with Leon D. Harmon, would cause Chuck Close to 'shit his pants' when their Block Portrait of Abraham Lincoln appeared on magazine covers on the opening day of Close's first "dot painting" exhibition. In contrast, the same cover would directly inspire one of Dalí's most famous works.

While one of the most influential and visible figures to emerge in the short history of digital art, reproductions of his artworks are limited, and surviving examples are next to impossible to source. The only known examples of his computer-generated work consist of the lost works exhibited in the Howard Wise exhibition and the 100 or so paperweights; no known print editions exist.

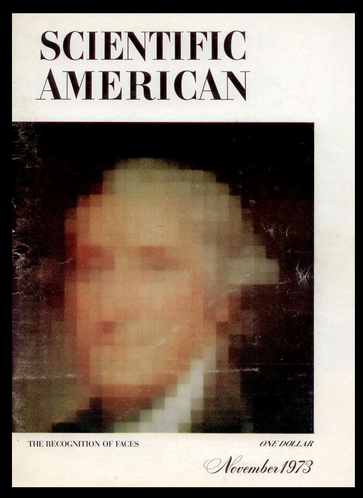
SALVADOR DALI PAINTING A 32 × 32 RANDOM DOT STEREOGRAM, C. 1970S
KINGDOM OF SPAIN, GALA-SALVADOR DALI FOUNDATION, VBK, VIENNA, 2005



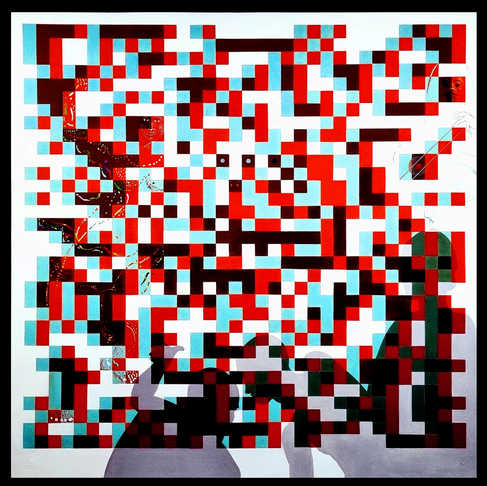
SCIENTIFIC AMERICAN, FEBRUARY 1965


JULY 1968 ONE DOLLAR
psychology today
This cover is an experiment a computer created it
Can you see through it?
(see special glasses, page 16)
In this issue: A Conversation with Abraham H. Maslow, President of the American Psychological Association

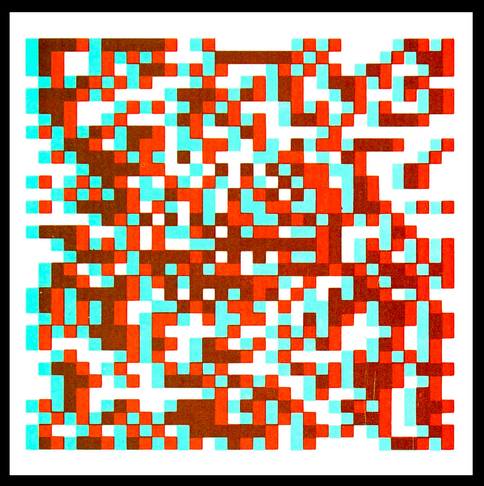
PSYCHOLOGY TODAY, JULY 1968



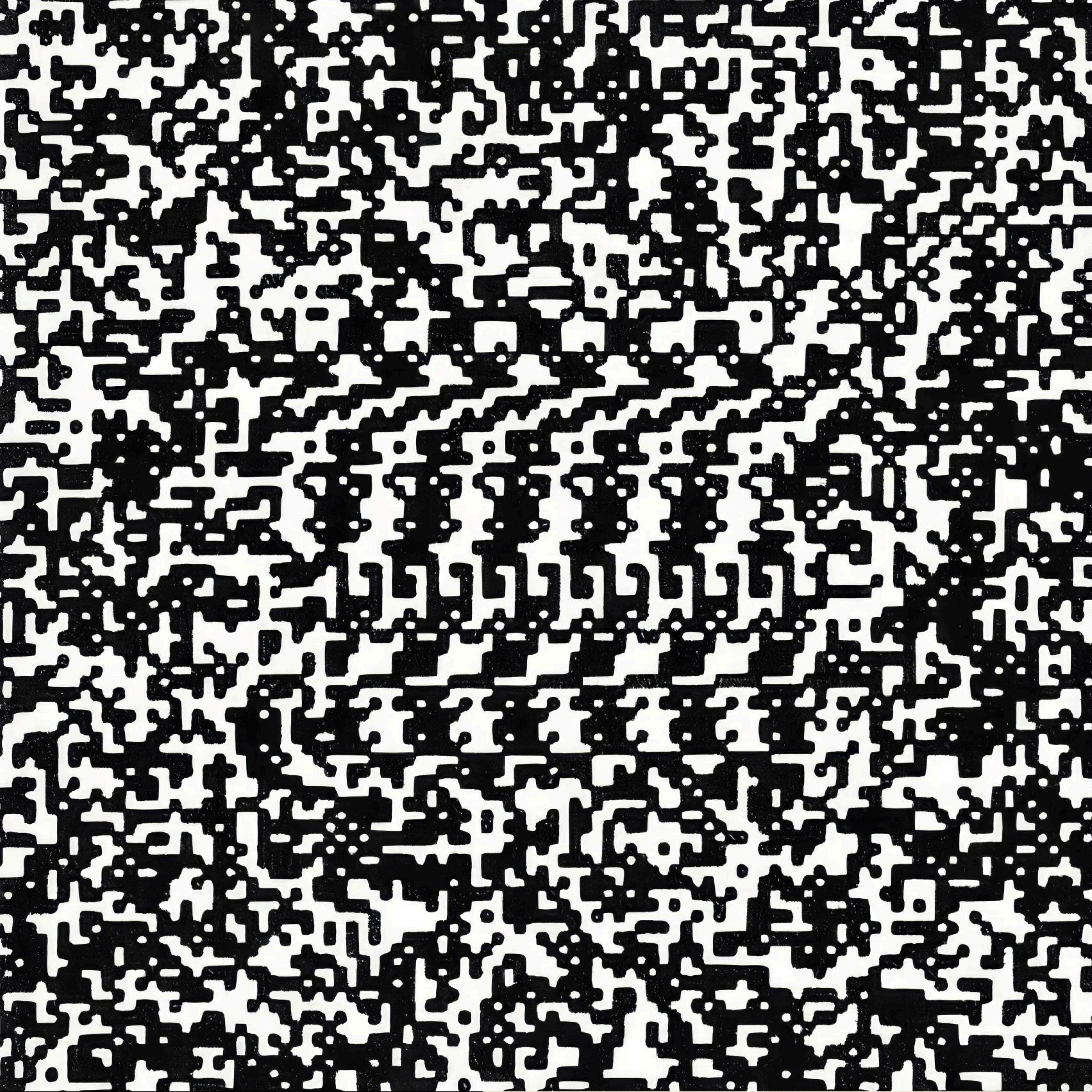
SCIENTIFIC AMERICAN, NOVEMBER 1973



CYBERNETIC ODALÍSQUE: HOMAGE TO BELA JULESZ BY SALVATOR DALI, 1978



RANDOM-DOT STEREOGRAM OF 33X33 RESOLUTION BY BELA JULESZ, 1971



THE HUMAN USE OF COMPUTING MACHINES

Gifted by Bell Laboratories to attendees of The Human Use of Computing Machines symposium in Murray Hill from June 20-21, 1966, the sculptural object contains an original Random Dot Stereogram created by Béla Julesz.

“A two-dimensional perspective work of computer art by me was used as the graphic theme for the symposium, and a 3D stereogram (along with a pair of polarized glasses) of a pattern by Bela Julesz was given to all the attendees as a memento of the symposium.”
NOLL, A. MICHAEL. “FIRST-HAND: AT&T VS BELL LABS.” ENGINEERING AND TECHNOLOGY HISTORY WIKI, 6 JAN. 2016.

Organized at the direction of William O. Baker, by Peter B. Denes and A. Michael Noll, The Human Use of Computing Machines was intended to showcase the breadth of the digital computers capacity within research applications throughout Bell Laboratories, Murray Hill. The symposium's name was conceived by A. Michael Noll, based on Norbert Wiener’s 1950 book title, The Human Use of Human Beings.

PORTRAIT OF A MICHAEL NOLL, C. 1974

“Dr. Baker realized the coming significance of the use of digital computers as a tool in research and wanted to make the academic community more aware of their application. He decided that the way to do this was to host a conference at Murray Hill to which academics would be invited from various universities around the country.”
NOLL, A. MICHAEL. MEMORIES: A PERSONAL HISTORY OF BELL TELEPHONE LABORATORIES. QUELLO CENTER, MICHIGAN STATE UNIVERSITY, 6 AUG. 2015.

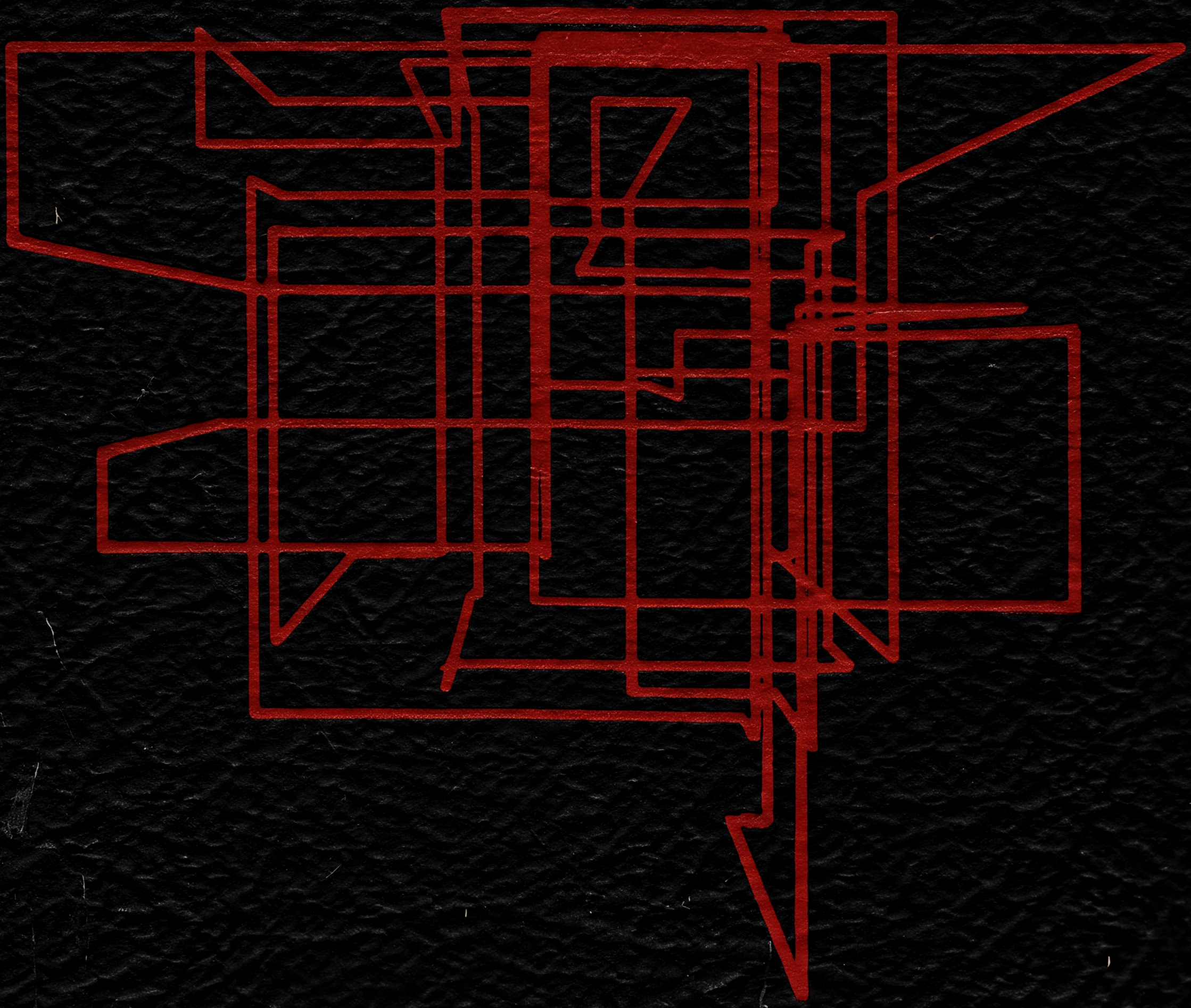
The symposium was organized at great expense to the laboratory, both in the time devoted to planning, and in the financial costs of attendee travel, lodging, and conference materials. Each presentation would be diligently rehearsed in advance, with each attendee receiving a textual summary upon arrival.

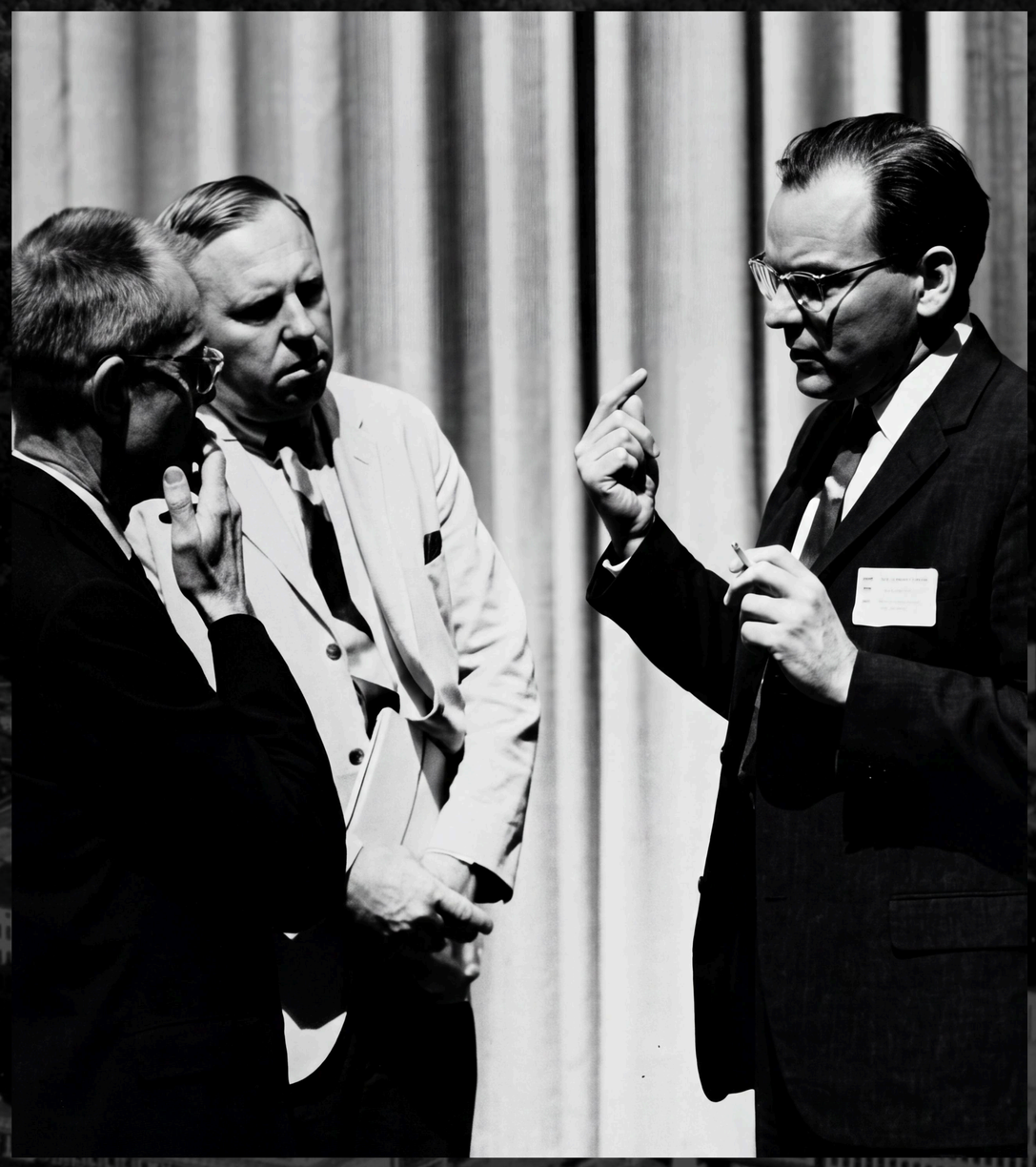
“The program demonstrated some of the many applications of computing machines which are being carried out at Bell Laboratories. It showed how more effective communication between people and computers can be achieved by developing special computer languages and by attaching special devices to computers. The papers illustrated various aspects of the revolution in computer technology and philosophy. The applications described included: design of electronic circuits, editing and typesetting of text, production of sounds and pictures for psychological experiments, speech research, carrying out of routine mathematical manipulations, and display of graphic output for educational films and other purposes.”
“A BTL SYMPOSIUM.” BELL TELEPHONE MAGAZINE, VOL. 45, NO. 3, AUTUMN 1966, PP. 48–49.

SIX REALIZATIONS (NO. SIX) BY A MICHAEL NOLL, 1965

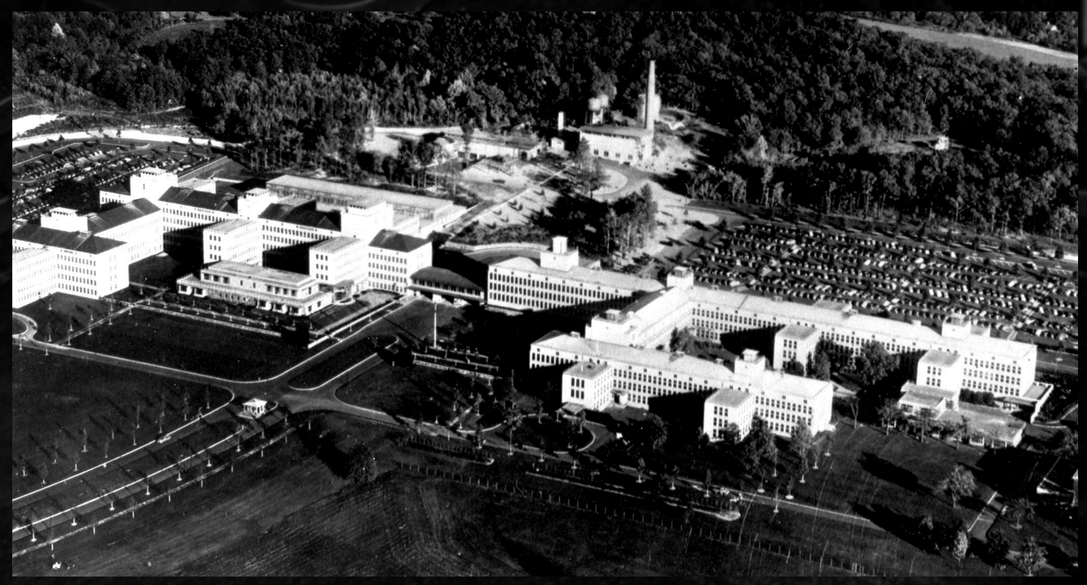
NOLL, A. MICHAEL. MEMORIES: A PERSONAL HISTORY OF BELL TELEPHONE LABORATORIES. QUELLO CENTER, MICHIGAN STATE UNIVERSITY, 6 AUG. 2015.

Based on an algorithm initially conceptualized for three dimensional stereo-pairs, the work is composed of a total of eighty-five vertical and horizontal line segments, with a different set of random numbers used for each realization. The composition would be used as the symposium's official logo, appearing on all promotions and materials.





JOHN R. PIERCE (RIGHT) SPEAKING WITH MANFRED R. SCHROEDER (RIGHT) AT THE HUMAN USE OF COMPUTING MACHINES SYMPOSIUM, BELL TELEPHONE LABORATORIES, MURRAY HILL (JUNE 20-21, 1966).
"A BTL SYMPOSIUM." BELL TELEPHONE MAGAZINE, VOL. 45, NO. 3, AUTUMN 1966, PP. 48–49.



BELL TELEPHONE LABORATORIES, MURRAY HILL, C. 1960S
PHOTOGRAPH, N.D. AIP EMILIO SEGRÈ VISUAL ARCHIVES, PHYSICS TODAY COLLECTION, CATALOG NO. BELL LABS H2, AMERICAN INSTITUTE OF PHYSICS.

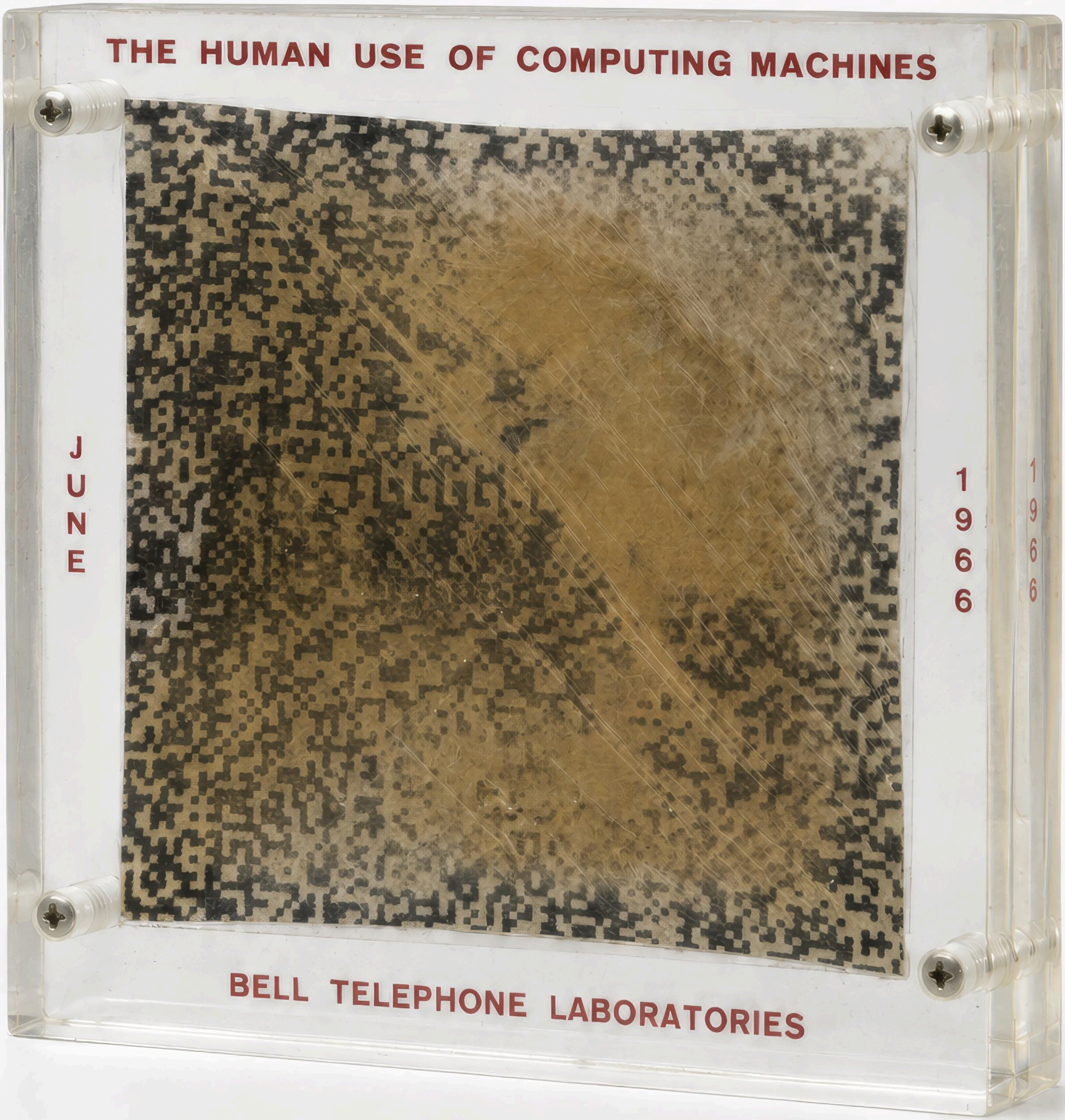
Retroactively, in seeming open defiance to AT&T's position on the discourse within the era, several computer-generated artworks by Bell Laboratories' engineers would be featured prominently throughout the event. Most visibly, all materials and promotions would contain the symposium's official logo, conceived and executed in 1965 by A. Michael Noll on the IBM 7094 computer. There would be several presentations on computer-generated animations, capturing the attention of attending journalists. Among these would include Kenneth Knowlton and Noll, presenting methods for the creation of two and three dimensional animations respectively, in addition to the latter's demonstration of the now infamous Computer-Generated Ballet (1965).

"Many examples of the use of computers in research were given to educate and interest the academics when they returned home to their institutions. A two-dimensional perspective work of computer art by me was used as the graphic theme for the symposium, and a 3D stereogram (along with a pair of polarized glasses) of a pattern by Bela Julesz was given to all the attendees as a memento of the symposium."
NOLL, A. MICHAEL. "FIRST-HAND: AT&T VS BELL LABS." ENGINEERING AND TECHNOLOGY HISTORY WIKI, 6 JAN. 2016.

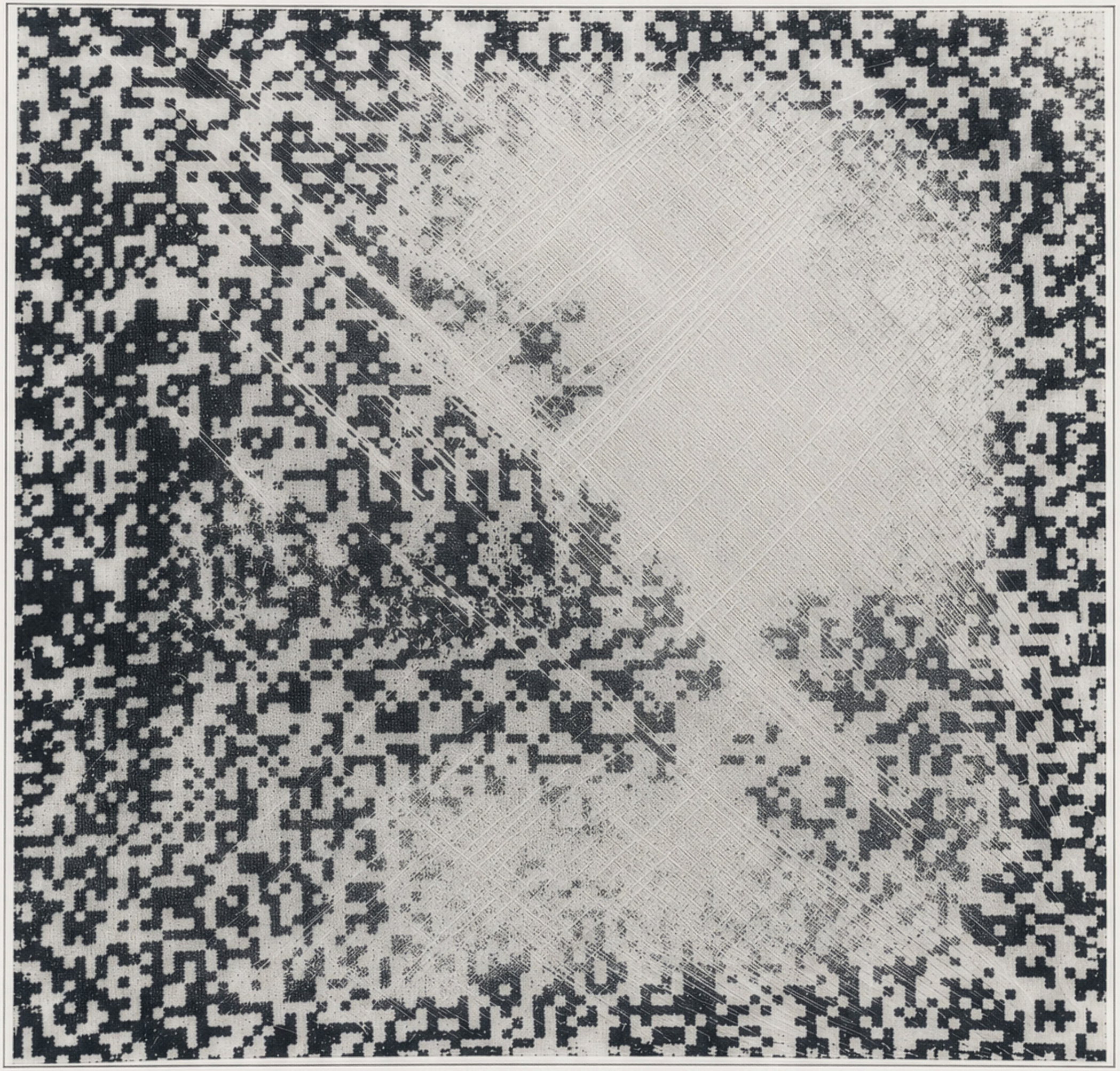
Attendees departed Bell Laboratories in 1966 not only with a new perspective of how the digital computer could assist academia, but also of its capacity to accelerate creativity. Moreover, each would return home with their own piece of computer-generated artwork in the form of a vectographic print of one of Bela Julesz's computer-generated stereograms, presented as a paperweight between lucite blocks.

COMPUTER-GENERATED STEREOGRAM BY BÉLA JULESZ , 1965/66

SURVIVING ARTIFACT, POLAROID VECTOGRAPH PRINT OF A RANDOM-DOT STEREOGRAM ENCASED IN LUCITE, 9.5 X 9.5 CM | COLLECTION OF NOAH BOLANOWSKI



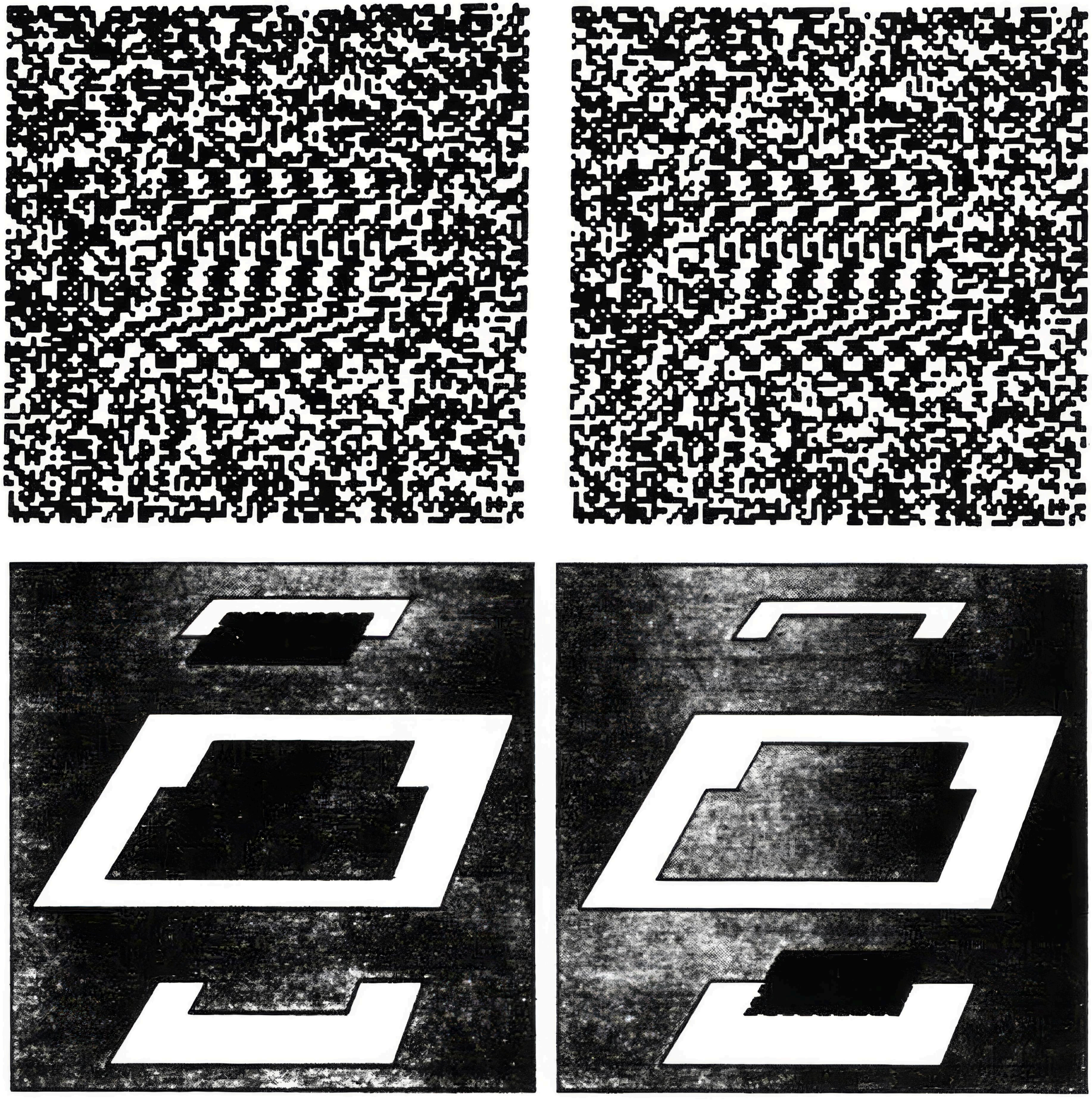
THE HUMAN USE OF COMPUTING MACHINES



JUNE

1966

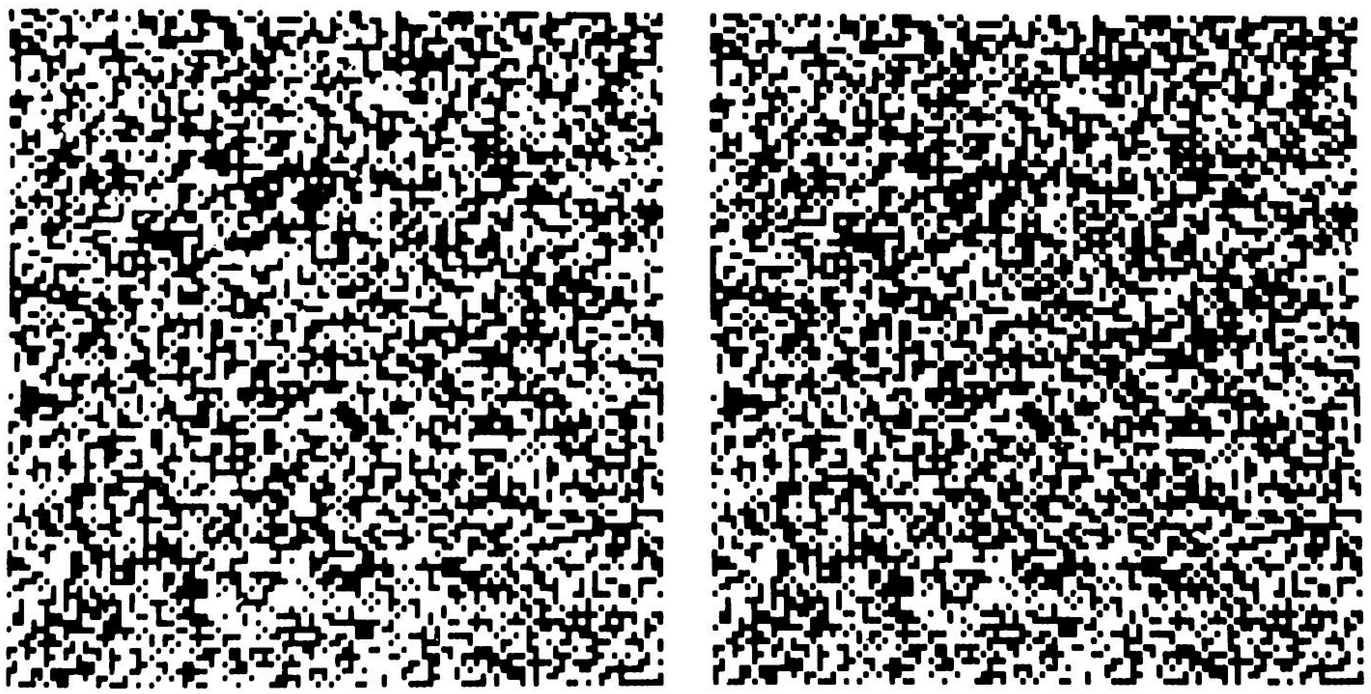
BELL TELEPHONE LABORATORIES



JULESZ, BELA. “COOPERATIVE PHENOMENA IN BINOCULAR DEPTH PERCEPTION: NOVEL STEREOSCOPIC DEMONSTRATIONS LEAD TO A SIMPLE MODEL THAT EXPLAINS MANY OF THESE COMPLEX PHENOMENA.” AMERICAN SCIENTIST, VOL. 62, NO. 1, JAN.–FEB. 1974, PP. 32–43.

COMPUTER-GENERATED RANDOM DOT STEREOGRAMS (1959-1968)

WEIBEL, PETER, EDITOR. BEYOND ART: A THIRD CULTURE: A COMPARATIVE STUDY IN CULTURES, ART AND SCIENCE IN 20TH CENTURY AUSTRIA AND HUNGARY. SPRINGERWIENNEWYORK, 2005, PP. 120–21



JULESZ, BELA. “COOPERATIVE PHENOMENA IN BINOCULAR DEPTH PERCEPTION_NOVEL STEREOSCOPIC DEMONSTRATIONS LEAD TO A SIMPLE MODEL THAT EXPLAINS MANY OF THESE COMPLEX PHENOMENA.” AMERICAN SCIENTIST, VOL. 62, NO. 1, JAN.–FEB. 1974, PP. 32–43.

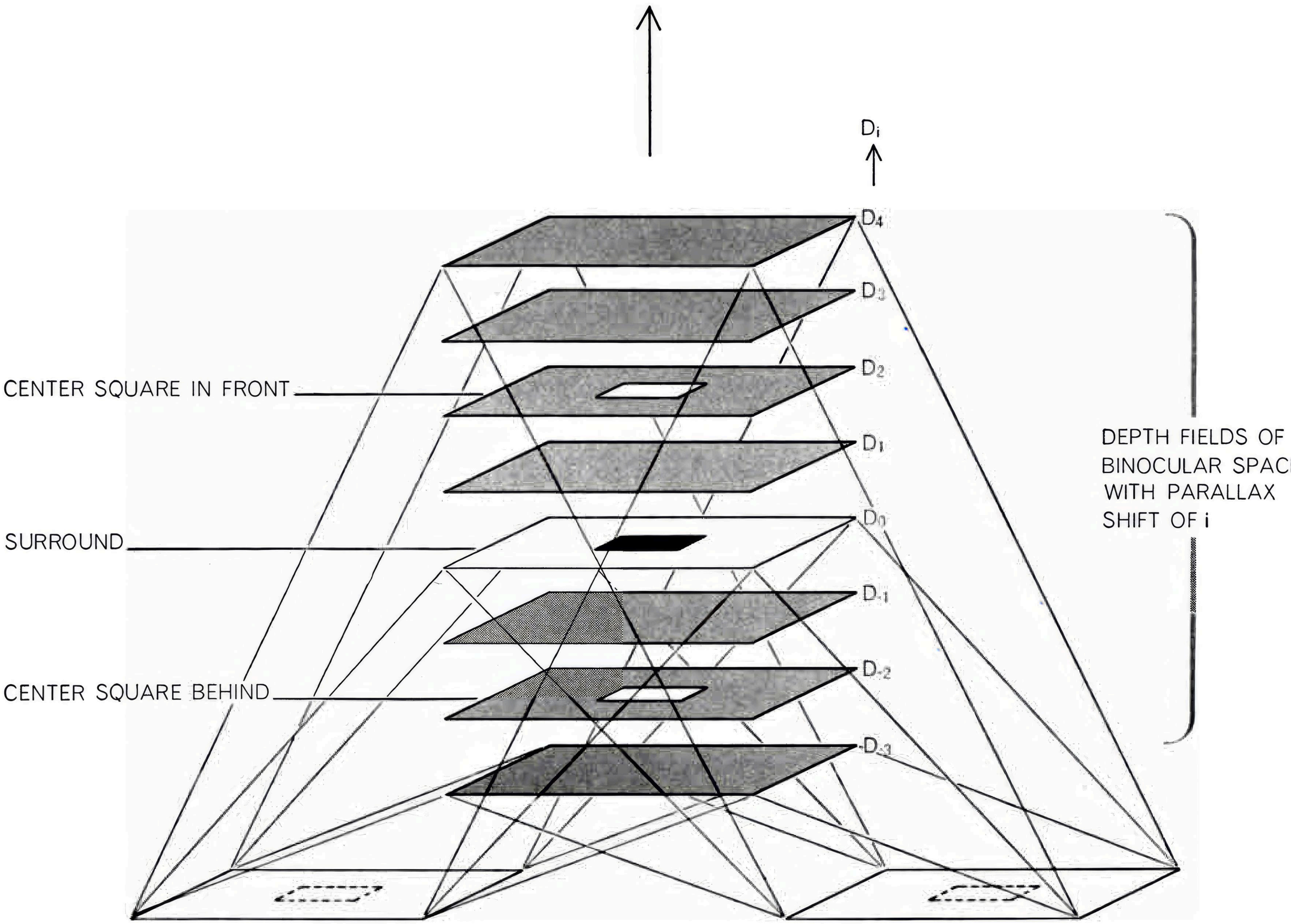
With his random-dot stereograms, Julesz created a new paradigm in brain research. He showed that there is hope that scientists will be able to successfully analyze perception, even though it is a very complex process that takes up more than half of the brain. Julesz generated the random-dot stereograms at a moment in the history of science when most people believed that the "problem of perception" would be solved by the end of the 1970s, and that soon, a "seeing" machine would prove that the problem had been solved. This optimistic approach was based on the assumption that visual perception is nothing but a collection of linear calculations. All that had to be done was to measure the differences in intensities of an image, and the contours that clearly define objects would appear.

In contrast, Julesz's stereograms demonstrated that contours are generated not only by intensity differences, but also by stereoscopic disparities (disparity is the minor difference between the two images). Also, because of the disparity among all other mechanisms used to perceive contours (such as changes in intensity, color, and movement), contour detection can be completely independent if there are no other cues in the monocular images. This made it possible to distinguish and study the subsystems of perception (e.g., stereo, color, or motion perception), and it became clear that these subsystems were capable of solving very complex tasks (just recall the difficulty of the correlation computation in the case of the two images above). Julesz's seminal work (Julesz 1964, 1965, 1966, 1971, 1975, 1981, 1991, 1995) gave rise to modern psychological physics, which, in conjunction with neurophysics, investigates these subsystems or modules.

The random-dot stereograms are a special case belonging to a more general class of images, which Julesz referred to (using Hering's and Helmholtz's terminology) as cyclopean images. Cyclopean images are seen by an imaginary cyclopean eye when the eyes are presented with stereoscopic images. Cyclopean vision occurs outside of the laboratory as well. Cyclopean vision is used by all creatures with stereovision in order to see objects in the environment in depth. Cyclopean vision has an important function beyond providing a rough estimation of depth. In the presence of cyclopean vision, camouflage is impossible. The prey that is perfectly camouflaged by the color or the two-dimensional pattern of its skin will be immediately visible as a threedimensional shape for the predator with cyclopean vision.

The notion of seeing through camouflage was important in the discovery of stereograms. Based on his earlier experience as a radar engineer, Julesz knew that there is no camouflage in three dimensions, and that led him to the idea of camouflaging the monocular images. There are many ways to generate examples of cyclopean vision. The classic method is to show a pair of images through a stereoscope. Practiced observers, however, might be able to free-fuse the stereograms without a stereoscope, by converging or diverging the eyes. In the anaglyph solution, one image is printed in red, the other is superimposed in green, and the observer views the images through red-green filters. The filters ensure that the views of the two eyes are isolated. Naturally, one needs a computer for all this (it is almost impossible to paint an anaglyph by hand), as is the case for random-dot cinematograms. Random-dot cinematograms appear on the computer screen as a sequence of random-dot sterograms. While there is only a dense dynamic noise in the monocular images, the cyclopean eye can see a moving object...

...The beauty of the three-dimensional shapes emerging from the random-dot clouds almost makes us forget that Julesz not only created patterns, he created a paradigm as well as a new field in science. The field of low-level vision, which has been amazingly developed over the last three decades, was originated by Julesz. According to Julesz's theory, low levels of perception can be studied separately from higher cognitive levels. There is a fast, automatic, parallel type of processing at the low levels. Focal attention selects a few elements from the rich output of these early levels for the slow, sequential, more conscious cognitive levels. Both this distinction and his structuralist approach helped him to bring us closer to an understanding of the human brain.



JULESZ, BELA. “COOPERATIVE PHENOMENA IN BINOCULAR DEPTH PERCEPTION: NOVEL STEREOSCOPIC DEMONSTRATIONS LEAD TO A SIMPLE MODEL THAT EXPLAINS MANY OF THESE COMPLEX PHENOMENA.” AMERICAN SCIENTIST, VOL. 62, NO. 1, JAN.–FEB. 1974, PP. 32–43.

COMPUTERS TURN TO MOVIE-MAKING

Bell Shows Five Films That Machines Have Produced

By JOHN NOBLE WILFORD

Special to The New York Times

MURRAY HILL, N. J., June 21—Computers are now getting into the movie-making business, though Doris Day and Rock Hudson need not fear for their jobs.

Engineers at Bell Telephone Laboratories here have completed production of seven animated black and white movies by computer, including one that describes the new technique. The movies range from simple line drawings to complex patterns with titles—all produced by computer.

Experiments with similar techniques involve drafting engineering plans and compiling three-dimensional maps from two-dimensional aerial photographs.

The animated films, used for education and research, can be produce faster and more economically by computers than by human draftsmen. In some cases, Bell engineers said, the process makes it possible to illustate scientific phenomena with a mathematical precision that humans have been unable to reproduce and film.

The Bell engineers who reported on the movie-making techniques are Kenneth C. Knowlton, A. Michael Noll and F. W. Sinden.

"Computer-generated movies are extremely useful in comparing mathematical models with reality and in depicting phenomena which are not directly observable," a spokesman said.

Computer-produced films, for example, could illustrate oscillations of electric current, the flow of air past a wing, or diffusion of heat.

Essentially, two pieces of equipment—the computer and a microfilm recorder—are needed to make such movies.

The microfilm recorder consists of a camera and a cathoderay picture tube, similar to a home television screen. The electron beam of the tube is controlled by signals from the computer or from a computer-transcribed magnetic tape.

First of all, the computer has been fed punched-card instructions for desired images. The special language for this is called Beflix, for Bell Flicks.

The screen starts out black. But to the computer, it is divided into an array of as many as 50,000 tiny squares, each of which can be given various shades of gray.

The computer plots where the light intensity should be varied to create a straight line, arc, curve, printed word or whatever image it has been instructed to form. The coordinates, which are fed to the microfilm recorder, are used to position the electron beam of the tube, and in this way trace out the desired picture on the face of the tube—not unlike a highly sophisticated version of drawing by the numbers.

When a full picture appears on the screen, the computer controlled camera snaps it. That is one frame of the film. It takes about 3,000 different frames to make a 17-minute animated movie.

More than 250 engineers and educators from across the nation saw these movies at a symposium on the Human Use of Computing Machines. The two-day meeting, sponsored by Bell Telephone Laboratories, ended today.

The Human Use of Computing Machines

The relation of man and computers has entered a new era, in which interaction is becoming quick and simple. A decade ago, use of computers seemed impractical for most scientists. Those conversant with the machines talked of the frustrating hours spent in programming, compiling, and debugging. There were long delays between concept and fruition, as users awaited their turn. Usually the computations merely took advantage of the fact that the new devices were much faster than desk calculators.

In this last decade the speed and memory of computers has been improved. Present-day models calculate 10^7 to 10^8 times as fast as a man does. These developments, however, are not so important as those which make for greater ease of using the machines. A sizable group of very competent men have created libraries of programs and subroutines. Some of them have turned their attention to other quick means of communicating with computers and to the complementary problem of obtaining information from the machine in a much more usable form.

An impressive sample of this progress was presented on 20 and 21 June at a symposium at the Bell Telephone Laboratories, Murray Hill, New Jersey. The audience numbered about 200 and included representatives from more than a hundred universities throughout the country. The group was truly interdisciplinary; it included substantial representation from the humanities, the social sciences, biology and medicine, the physical sciences, and, of course, mathematics and engineering.

At the Bell Laboratories some 1400 men spend at least half their time working with computers, of which 40 are available. These include special-purpose computers for on-line problem solving, a console for handling pictorial input and output, and a computer which takes graphic or symbolic input and delivers auditory output. Under design is a system in which a central machine will serve 200 to 300 typewriter consoles and contain an elaborate program library.

Today, instructions to a computer can often be conveyed by typing simple English or abbreviations. Another means of easy access to the computer is through a console that employs something similar to an oscilloscope screen and a light pen. The computer converts a rough sketch into a finished drawing. Block circuit drawings can be quickly assembled through a series of instructions mediated by a light pen.

The computer can communicate with the user in new, simple forms. To the scientist, perhaps the most impressive development is the graphic presentation of data. Earlier, the output from the machine usually took the form of almost indigestible quantities of printed results. Today a glance at a curve on a screen or the plot of a thousand points can provide an almost instant summation of the same output. Another impressive development is that of teaching a computer to talk. Through manipulation of controls, the investigator can change the character and emphasis of the speech. This work seems to be speeding the day when it will become possible to speak to a computer and to obtain quickly a spoken as well as a visible output.

Improvements in computers and in the ease of using them portend a further great expansion in their use in all the sciences and in many of the humanities. "After growing wildly for years the field of computing now appears to be approaching its infancy."—PHILIP H. ABELSON

A method for Doris to keep day forever

By MARK N. FINSTON

A computer will never replace Doris Day, at least for the movie screen.

Replacing the real, live Doris Day with a picture manufactured by a computer might not be such a ridiculous idea. After all, human beings age, sometimes to the point where they can no longer play those frivolous young parts they have portrayed for the last 20 years.

But an image created by a computer would be ageless. The ambitious producer could even make new movies starring Jean Harlow or Marilyn Monroe.

Doris Day
Image would be ageless

ANIMATED BUGS

"I doubt the day will ever come," sighed Kenneth C. Knowlton, a member of the Computing Techniques Research Department at the Bell Telephone Laboratories in Murray Hill. "If I tried to do it, it would take the rest of my life plus hundreds of thousands of dollars of computer money just to make five minutes of Doris Day."

Knowlton did not say if he is a Doris Day fan, but he did note a computer of his has just completed a movie featuring animated bugs.

"It was a technical movie," explained Knowlton. "Had it been a cartoon, I would have wanted more realistic bugs. Mine look pretty flat."

The subject of making movies by computer was discussed yesterday as Bell's two-day symposium on "The Human Use of Computing Machines" drew to a close at the vast Union County research facility. Some 200 educators from all over the country attended the conference.

PLUMP IDEA

Doris Day's problem is that she's too complicated. A computer would have to learn to reproduce Doris waving, weeping or giggling or whatever else she does on the silver screen. Meticulous care would have to be paid to reproduce each bone of her skeleton, each pound of her skin in the computer's memory.

"I suppose it would be easier to program a fat person," mused Knowlton. "You wouldn't notice a one-inch error."

Well, if poor Doris must continue to rely on heavier makeup instead of computer savvy to play those 20-year-old man-huntresses, other uses are being found for computer-manufactured movies. These primarily concern scenes ordinarily unavailable to the human eye.

For example, a movie shown at the symposium portrayed the workings of the basilar membrane, located in the ear. Different sounds cause the membrane to vibrate in different ways. By feeding the computer all sorts of mathematical information, the vibration can be recreated on the movie screen—and enlarged from the one-one millionth of a centimeter which is the size of what actually goes on in the ear.

A. Michael Noll, of Bell's acoustics research department, made a computer movie which might be helpful to choreographers. Unlike a musical piece, each note of which can be recorded or written down, there is a problem of preserving a work of dance, once all the principals are dead. So why not allow the computer to "remember" and be able to reproduce every movement of all the dancers throughout the work?

Noll's movie, using six "stick" figures moving at random in dance motions, showed it can be done.

And Knowlton says it won't be long before computer

Reporter at Large

movies will be of use to the architect. Assume the architect is in the midst of designing a still hypothetical complex of buildings.

DOWN NOW

The architect wants to visualize what it would look like if he walked through a particular hallway, or what view he would get if he drove his car past the future structures on a street nearby. The computer could figure out the scene from every conceivable angle.

"It's being done experimentally now," said Knowlton. "In 10 years this type of thing will be an important part of architecture."

Knowlton noted that buildings can be programmed more easily than Doris Days. Buildings rarely wave, weep or giggle.

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